VISIT…

3 Maintenance Management and Control

INTRODUCTION

The management and control of maintenance activities are equally important to performing maintenance. Maintenance management may be described as the function of providing policy guidance for maintenance activities, in addition to exercising technical and management control of maintenance programs.[1,2] Generally, as the size of the maintenance activity and group increases, the need for better management and control become essential.

In the past, the typical size of a maintenance group in a manufacturing establishment varied from 5 to 10% of the operating force.[3] Today, the proportional size of the maintenance effort compared to the operating group has increased significantly, and this increase is expected to continue. The prime factor behind this trend is the tendency in industry to increase the mechanization and automation of many processes. Consequently, this means lesser need for operators but greater requirement for maintenance personnel.

There are many areas of maintenance management and control. This chapter presents some of the important ones.

MAINTENANCE DEPARTMENT FUNCTIONS AND ORGANIZATION

A maintenance department is expected to perform a wide range of functions including:[4–6]

- Planning and repairing equipment/facilities to acceptable standards
- Performing preventive maintenance; more specifically, developing and implementing a regularly scheduled work program for the purpose of maintaining satisfactory equipment/facility operation as well as preventing major problems
- Preparing realistic budgets that detail maintenance personnel and material needs
- Managing inventory to ensure that parts/materials necessary to conduct maintenance tasks are readily available
- Keeping records on equipment, services, etc.

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- Developing effective approaches to monitor the activities of maintenance staff
- Developing effective techniques for keeping operations personnel, upper-level management, and other concerned groups aware of maintenance activities
- Training maintenance staff and other concerned individuals to improve their skills and perform effectively
- Reviewing plans for new facilities, installation of new equipment, etc.
- Implementing methods to improve workplace safety and developing safety education-related programs for maintenance staff
- Developing contract specifications and inspecting work performed by contractors to ensure compliance with contractual requirements

Many factors determine the place of maintenance in the plant organization including size, complexity, and product produced. The four guidelines useful in planning a maintenance organization are: establish reasonably clear division of authority with minimal overlap, optimize number of persons reporting to an individual, fit the organization to the personalities involved, and keep vertical lines of authority and responsibility as short as possible.[5]

One of the first considerations in planning a maintenance organization is to decide whether it is advantageous to have a centralized or decentralized maintenance function. Generally, centralized maintenance serves well in small- and medium-sized enterprises housed in one structure, or service buildings located in an immediate geographic area. Some of the benefits and drawbacks of centralized maintenance are as follows:[3]

Benefits

- More efficient compared to decentralized maintenance
- Fewer maintenance personnel required
- More effective line supervision
- Greater use of special equipment and specialized maintenance persons
- Permits procurement of more modern facilities
- Generally allows more effective on-the-job training

Drawbacks

- Requires more time getting to and from the work area or job
- No one individual becomes totally familiar with complex hardware or equipment
- More difficult supervision because of remoteness of maintenance site from the centralized headquarters
- Higher transportation cost due to remote maintenance work

In the case of decentralized maintenance, a maintenance group is assigned to a particular area or unit. Some important reasons for the decentralized maintenance are to reduce travel time to and from maintenance jobs, a spirit of cooperation between production and maintenance workers, usually closer supervision, and higher

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chances for maintenance personnel to become familiar with sophisticated equipment or facilities.

Past experience indicates that in large plants a combination of centralized and decentralized maintenance normally works best. The main reason is that the benefits of both the systems can be achieved with essentially a low number of drawbacks. Nonetheless, no one particular type of maintenance organization is useful for all types of enterprises.

MAINTENANCE MANAGEMENT BY OBJECTIVES, CRITICAL MAINTENANCE MANAGEMENT PRINCIPLES, AND MAINTENANCE PROGRAM EFFECTIVENESS EVALUATION QUESTIONS FOR MAINTENANCE MANAGERS

Improving a maintenance management program is a continuous process that requires progressive attitudes and active involvement. A nine-step approach for managing a maintenance program effectively is presented below:[6]

- *Identify existing deficiencies.* This can be accomplished through interviews with maintenance personnel and by examining in-house performance indicators.
- *Set maintenance goals.* These goals take into consideration existing deficiencies and identify targets for improvement.
- *Establish priorities.* List maintenance projects in order of savings or merit.
- *Establish performance measurement parameters.* Develop a quantifiable measurement for each set goal, for example, number of jobs completed per week and percentage of cost on repair.
- *Establish short- and long-range plans.* The short-range plan focuses on high-priority goals, usually within a one-year period. The long-range plan is more strategic in nature and identifies important goals to be reached within three to five years.
- *Document both long- and short-range plans and forward copies to all concerned individuals.*
- *Implement plan.*
- *Report status.* Preparing a brief report periodically, say semi-annually, and forward it to all involved individuals. The report contains for each objective identified in the short-range plan information on actual or potential slippage of the schedule and associated causes.
- *Examine progress annually.* Review progress at the end of each year with respect to stated goals. Develop a new short-range plan for the following year by considering the goals identified in the long-range plan and adjustments made to the previous year's planned schedule, resources, costs, and so on.

Over the years many maintenance management principles have been developed. Table 3.1 presents six critical maintenance management principles. These principles,

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TABLE 3.1
Important Maintenance Management Principles

No.	Principle	Brief Description
1	Maximum productivity results when each involved person in an organization has a defined task to perform in a definitive way and a definite time.	This principle of scientific management formulated by Frederick W. Taylor in the late nineteenth century remains an important factor in management.[7,8]
2	Schedule control points effectively.	Schedule control points at intervals such that the problems are detected in time, thus the scheduled completion of the job is not delayed.
3	Measurement comes before control.	When an individual is given a definitive task to be accomplished using a good representative approach in a specified time, he/she becomes aware of management expectations. Control starts when managing supervisors compare the results against set goals.
4	The customer service relationship is the basis of an effective maintenance organization.	A good maintenance service is an important factor in maintaining facilities at an expected level effectively. The team approach fostered by the organizational setup is crucial to consistent, active control of maintenance activity.
5	Job control depends on definite, individual responsibility for each activity during the life span of a work order.	It is the responsibility of the maintenance department to develop, implement, and provide operating support for the planning and scheduling of maintenance work. It is the responsibility of the supervisory individuals to ensure proper and complete use of the system within their sphere of control.
6	The optimal crew size is the minimum number that can perform an assigned task effectively.	Most tasks require only one individual.

if applied on a regular basis, can help make a maintenance department productive and successful.[7]

The U.S. Energy Research and Development Administration conducted a study on maintenance management-related matters and formulated the following ten questions for maintenance managers to self-evaluate their maintenance effort:[8]

1. Are you aware of how your craftpersons spend their time; i.e., travel, delays, etc.?
2. Are you aware of what facility/equipment and activity consume most of the maintenance money?
3. Are you aware if the craftpersons use proper tools and methods to perform their tasks?

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4. Have you balanced your spare parts inventory with respect to carrying cost vs. anticipated downtime losses?
5. With respect to job costs, are you in a position to compare the "should" with the "what"?
6. Do you ensure that maintainability factors are considered properly during the design of new or modified facilities/equipment?
7. Are you aware of how much time your foreman spends at the desk and at the job site?
8. Do you have an effective base to perform productivity measurements, and is productivity improving?
9. Are you aware of whether safety practices are being followed?
10. Are you providing the craftpersons with correct quality and quantity of material when and where they need it?

If an unqualified "yes" is the answer to each of the above questions, then your maintenance program is on a sound footing to meet organizational objectives. Otherwise, appropriate corrective measures are required.

ELEMENTS OF EFFECTIVE MAINTENANCE MANAGEMENT

There are many elements of effective maintenance management whose effectiveness is the key to the overall success of the maintenance activity. Many of these elements are described below.[6,8]

Maintenance Policy

A maintenance policy is one of the most important elements of effective maintenance management. It is essential for continuity of operations and a clear understanding of the maintenance management program, regardless of the size of a maintenance organization. Usually, maintenance organizations have manuals containing items such as policies, programs, objectives, responsibilities, and authorities for all levels of supervision, reporting requirements, useful methods and techniques, and performance measurement indices. Lacking such documentation, i.e., a policy manual, a policy document must be developed containing all essential policy information.

Material Control

Past experience indicates that, on average, material costs account for approximately 30 to 40% of total direct maintenance costs.[8] Efficient utilization of personnel depends largely on effectiveness in material coordination. Material problems can lead to false starts, excess travel time, delays, unmet due dates, etc. Steps such as job planning, coordinating with purchasing, coordinating with stores, coordination of issuance of materials, and reviewing the completed job can help reduce material-related problems.

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Deciding whether to keep spares in storage is one of the most important problems of material control. The subject of inventory control is discussed in detail in Chapter 7.

Work Order System

A work order authorizes and directs an individual or a group to perform a given task. A well-defined work order system should cover all the maintenance jobs requested and accomplished, whether repetitive or one-time jobs. The work order system is useful for management in controlling costs and evaluating job performance. Although the type and size of the work order can vary from one maintenance organization to another, a work order should at least contain information such as requested and planned completion dates, work description and its reasons, planned start date, labor and material costs, item or items to be affected, work category (preventive maintenance, repair, installation, etc.), and appropriate approval signatures.

Equipment Records

Equipment records play a critical role in effectiveness and efficiency of the maintenance organization. Usually, equipment records are grouped under four classifications: maintenance work performed, maintenance cost, inventory, and files. The maintenance work performed category contains chronological documentation of all repairs and preventive maintenance (PM) performed during the item's service life to date. The maintenance cost category contains historical profiles and accumulations of labor and material costs by item. Usually, information on inventory is provided by the stores or accounting department. The inventory category contains information such as property number, size and type, procurement cost, date manufactured or acquired, manufacturer, and location of the equipment/item. The files category includes operating and service manuals, warranties, drawings, and so on.

Equipment records are useful when procuring new items/equipment to determine operating performance trends, troubleshooting breakdowns, making replacement or modification decisions, investigating incidents, identifying areas of concern, performing reliability and maintainability studies, and conducting life cycle cost and design studies.

Preventive and Corrective Maintenance

The basic purpose of performing PM is to keep facility/equipment in satisfactory condition through inspection and correction of early-stage deficiencies. Three principle factors shape the requirement and scope of the PM effort: process reliability, economics, and standards compliance.

A major proportion of a maintenance organization's effort is spent on corrective maintenance (CM). Thus, CM is an important factor in the effectiveness of maintenance organization. Both PM and CM are described in detail in Chapters 4 and 5.

Job Planning and Scheduling

Job planning is an essential element of the effective maintenance management. A number of tasks may have to be performed prior to commencement of a maintenance job; for example, procurement of parts, tools, and materials, coordination and delivery

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of parts, tools, and materials, identification of methods and sequencing, coordination with other departments, and securing safety permits.

Although the degree of planning required may vary with the craft involved and methods used, past experience indicates that on average one planner is required for every twenty craftpersons. Strictly speaking, formal planning should cover 100% of the maintenance workload but emergency jobs and small, straightforward work assignments are performed in a less formal environment. Thus, in most maintenance organizations 80 to 85% planning coverage is attainable.

Maintenance scheduling is as important as job planning. Schedule effectiveness is based on the reliability of the planning function. For large jobs, in particular those requiring multi-craft coordination, serious consideration must be given to using methods such as Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) to assure effective overall control. The CPM approach is described in detail later in this chapter.

Backlog Control and Priority System

The amount of backlog within a maintenance organization is one of the determining factors of maintenance management effectiveness. Identification of backlogs is important to balance manpower and workload requirements. Furthermore, decisions concerning overtime, hiring, subcontracting, shop assignments, etc., are largely based on backlog information. Management makes use of various indices to make backlog-related decisions.

The determination of job priority in a maintenance organization is necessary since it is not possible to start every job the day it is requested. In assigning job priorities, it is important to consider factors such as importance of the item or system, the type of maintenance, required due dates, and the length of time the job awaiting scheduling will take.

Performance Measurement

Successful maintenance organizations regularly measure their performance through various means. Performance analyses contribute to maintenance department efficiency and are essential to revealing the downtime of equipment, peculiarities in operational behavior of the concerned organization, developing plans for future maintenance, and so on. Various types of performance indices for use by the maintenance management are discussed later in this chapter.

MAINTENANCE PROJECT CONTROL METHODS

Two widely used maintenance project control methods are Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM). The development of PERT is associated with the U.S. Polaris project to monitor the effort of 250 prime contractors and 9000 subcontractors. PERT was the result of efforts of a team formed by the U.S. Navy's Special Project Office in 1958. Team members included the consulting firm of Booz, Allen, and Hamilton and the Lockheed Missile System Division.[9–12]

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The history of CPM can be traced to 1956 when E.I. duPont de Nemours and Co. used a network model to schedule design and construction activities. The following year, CPM was used in the construction of a $10 million chemical plant in Louisville, Kentucky.

In maintenance and other projects three important factors of concern are time, cost, and resource availability. CPM and PERT deal with these factors individually and in combination.

PERT and CPM are similar. The major difference between the two is that when the completion times of activities of the project are uncertain, PERT is used and with the certainty of completion times, CPM is employed.[11]

The following steps are involved with PERT and CPM:[12]

- Break a project into individual jobs or tasks.
- Arrange these jobs/tasks into a logical network.
- Determine duration time of each job/task.
- Develop a schedule.
- Identify jobs/tasks that control the completion of project.
- Redistribute resources or funds to improve schedule.

The following sections present a formula to estimate activity expected duration times and CPM in detail.

Activity Expected Duration Time Estimation

The PERT scheme calls for three estimates of activity duration time using the following formula to calculate the final time:

$$T_a = \frac{\mathrm{OT} + 4(\mathrm{MT}) + \mathrm{PT}}{6} \tag{3.1}$$

where

T_a = activity expected duration time,
OT = optimistic or minimum time an activity will require for completion,
PT = pessimistic or maximum time an activity will require for completion,
MT = most likely time an activity will require for completion. This is the time used for CPM activities.

Equation (3.1) is based on Beta distribution.[13]

Example 3.1

Assume that we have the following time estimates to accomplish an activity:

- OT = 55 days
- PT = 80 days
- MT = 60 days

Calculate the activity expected duration time.

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Substituting the given data into Eq. (3.1), we get

$$T_a = \frac{55 + 4(60) + 80}{6} = 62.5 \text{ days}$$

The expected duration time for the activity is 62.5 days.

Critical Path Method (CPM)

Four symbols used to construct a CPM network are shown in Fig. 3.1. The circle denotes an event. Specifically, it represents an unambiguous point in the life of a project. An event could be the start or completion of an activity or activities, and usually the events are labeled by number. A circle shown with three divisions in Fig. 3.1(b) is also denotes an event. Its top half labels the event with a number, and the bottom portions indicate latest event time (LET) and earliest event time (EET). LET may be described as the latest time in which an event can be reached without delaying project completion. EET is the earliest time in which an activity can be accomplished or an event could be reached.

The continuous arrow represents an activity that consumes time, money, and manpower. This arrow always starts at a circle and ends at a circle. The dotted arrow denotes a dummy activity or a restraint. Specifically, this is an imaginary activity that does not consume time, money, or manpower. Figure 3.2 depicts an application of a dummy activity. It shows that activities L and M must be accomplished before activity N can start. However, only activity M must be completed prior to starting activity O.

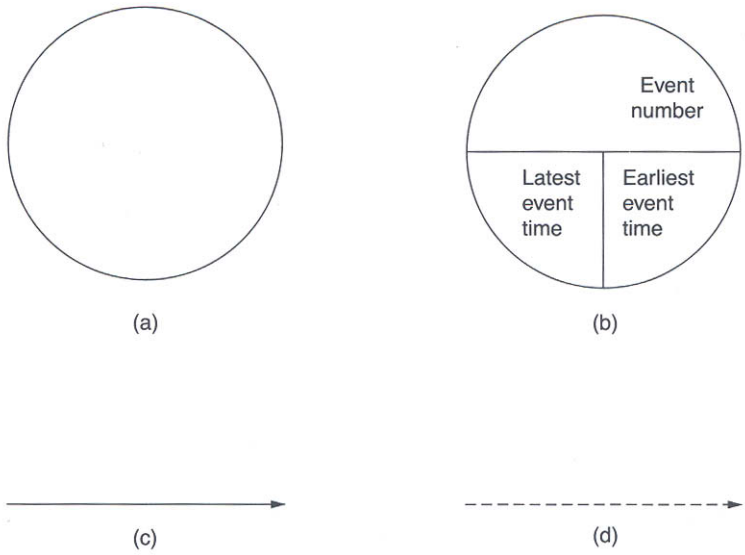

FIGURE 3.1 CPM symbols: (a) circle, (b) circle with divisions, (c) continuous arrow, (d) dotted arrow.

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TABLE 3.2
Maintenance Project Activities' Associated Data

Activity Identification	Immediate Predecessor Activity or Activities	Expected Duration in Days
L	–	12
M	–	2
N	L, M	2
O	L	6
P	O	3
S	N, P	9
T	S	15

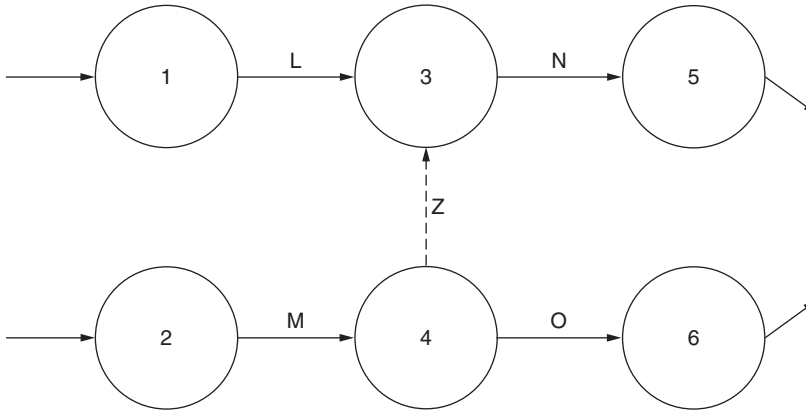

FIGURE 3.2 A portion of a CPM network with a dummy activity.

Example 3.2

A maintenance project was broken down into a set of seven activities, after which Table 3.2 was prepared. Prepare a CPM network using Fig. 3.1 symbols and Table 3.2 data, and determine the critical path associated with the network. A CPM network for given data in Table 3.2 is presented in Fig. 3.3.

In this figure, the following paths originate and terminate at events 1 and 7, respectively:

- M–N–S–T (2 + 2 + 9 + 15 = 28 days)
- L–X–N–S–T (12 + 0 + 2 + 9 + 15 = 38 days)
- L–O–P–S–T (12 + 6 + 3 + 9 + 15 = 45 days)

The quantities in parentheses above show the total time in days for each path. The dummy activity consumes zero time. By definition, the longest path through the network is the critical path. Inspection of the above three values shows that 45 days is

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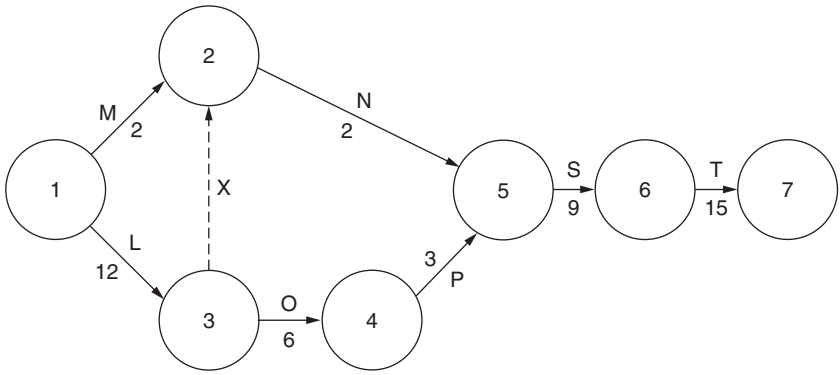

FIGURE 3.3 A CPM network for Table 3.2 data.

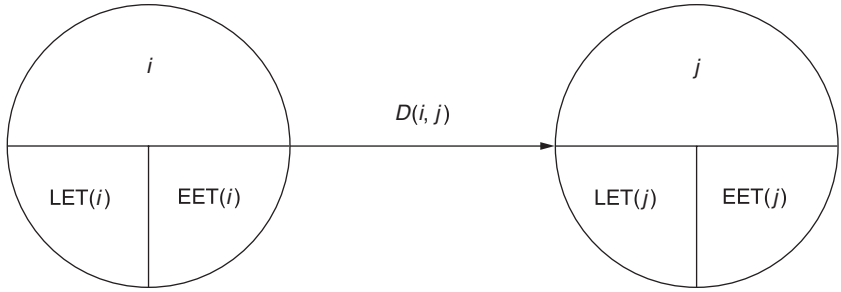

FIGURE 3.4 A single activity CPM network.

the largest time. Specifically, it will take 45 days from event 1 to reach event 7. Thus, this is the critical path. The word "critical" is used because any delay in the completion of activities along the critical path will result in delay of completion of the maintenance project.

Critical Path Determination Approach

For simple and straightforward CPM networks, the critical path can easily be identified in a manner discussed above. For complex networks a more systematic approach is required. This section presents one such approach with the aid of Fig. 3.4. The symbols used in the figure are defined below.

EET(i) = earliest event time of event i
EET(j) = earliest event time of event j
LET(i) = latest event time of event i
LET(j) = latest event time of event j
$D(i, j)$ = expected duration time of the activity between events i and j

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The following steps are associated with the approach:

1. Construct CPM network.
2. Calculate EET of each event by making a forward pass of the network and using: For any event j,

$$\text{EET}(j) = \text{Maximum for all preceding } i \text{ of } [\text{EET}(i) + D(i,j)] \tag{3.2}$$

   Also,

$$\text{EET}(\text{first event}) = 0 \tag{3.3}$$

3. Calculate LET of each event by making a backward pass of the network and using: For any event i,

$$\text{LET}(i) = \text{Minimum for all succeeding } j \text{ of } [\text{LET}(j) + D(i,j)] \tag{3.4}$$

   Also,

$$\text{LET}(\text{last event}) = \text{EET}(\text{last event}) \tag{3.5}$$

   If LET of all events of the network in question was calculated correctly, we should get

$$\text{LET}(\text{first event}) = 0 \tag{3.6}$$

4. Select network events with equal EET and LET. If the network results in only one path, i.e., from the first event to the last event, with EET = LET, this path is critical. Otherwise, go to next step.
5. Calculate the total float for each activity on each of the paths with EET = LET. The critical path is the path that results in the least sum of the total floats. The total float for any activity (i, j) can be calculated using the following equation:

$$\text{Total float} = \text{LET}(j) - \text{EET}(i) - D(i,j) \tag{3.7}$$

Example 3.3

Determine the critical path by calculating EET and LET of each event of the network shown in Fig. 3.3.

Using Eq. (3.2) we obtain EET of events 1, 2, 3, 4, 5, 6, and 7 as 0, 12, 12, 18, 21, 30, and 45, respectively. Similarly, with the aid of Eq. (3.4) the LET of events 1, 2, 3, 4, 5, 6, and 7 are 0, 19, 12, 18, 21, 30, and 45, respectively. Figure 3.5 shows

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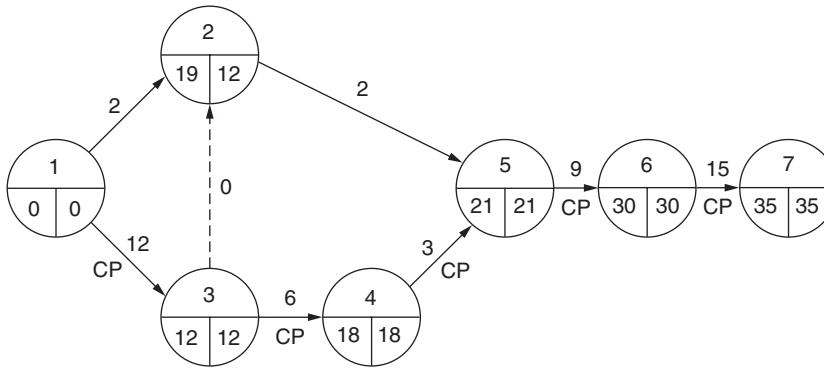

FIGURE 3.5 Redrawn Fig. 3.3 network with EETs and LETs.

a redrawn Fig. 3.3 CPM network with these EETs and LETs. The lower left quarter of each circle in Fig. 3.5 shows LET and the right right quarter the EET. The activities marked CP in Fig. 3.5 indicate the critical path as all the events that fall on this path have EET = LET, and it is the only path whose events have equal EETs and LETs. In other two paths the EET and LET of all events encountered are not equal.

CPM Advantages and Disadvantages

As with other methods, CPM has its advantages and disadvantages. Some of the CPM advantages are as follows:[14]

- It is an effective tool for monitoring project progress.
- It helps improve project understanding and communication among involved personnel.
- It highlights activities important to complete the project on time. These activities must be completed on time to accomplish the entire project on predicted time.
- It shows interrelationships in workflow and is useful in determining labor and resources needs in advance.
- It is an effective tool for controling costs and can easily be computerized.
- It helps avoiding duplications and omissions and determining project duration systematically.

Some of the disadvantages of the CPM are as follows:[14]

- Costly
- Time-consuming
- Poor estimates of activity times
- Inclination to use pessimistic estimates for activity times

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MAINTENANCE MANAGEMENT CONTROL INDICES

Management employs various approaches to measure effectiveness of the maintenance function. Often it uses indices to manage and control maintenance. These indices show trends by using past data as a reference point. Usually, a maintenance organization employs various indices to measure maintenance effectiveness, as there is no single index that can accurately reflect the overall performance of the maintenance activity. The main objective of these indices is to encourage maintenance management to improve on past performance.

This section presents a number of broad and specific indices.[3,7,15,16] The broad indices indicate the overall performance of the organization with respect to maintenance and the specific indices indicate the performance in particular areas of the maintenance function. The values of all these indices are plotted periodically to show trends.

Broad Indicators

This section presents three such indicators.

Index I

This is defined by

$$I_1 = \frac{\text{TMC}}{\text{TS}} \tag{3.8}$$

where

TMC = total maintenance cost,
TS = total sales,
I_1 = index parameter.

Past experience indicates that average expenditure for maintenance for all industry was around 5% of sales. However, there was a wide variation among industries. For example, the average values of I_1 for steel and chemical industries were 12.8 and 6.8%, respectively.

Index II

This is expressed by

$$I_2 = \frac{\text{TMC}}{\text{TO}} \tag{3.9}$$

where

TO = total output expressed in gallons, tons, megawatts, etc.,
I_2 = index parameter.

This index relates the total maintenance cost to the total output by the organization.

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Index III

This is defined as follows:

$$I_3 = \frac{\text{TMC}}{\text{TIPE}} \tag{3.10}$$

where
I_3 = index parameter,
TIPE = total investment in plant and equipment.

This index relates the total maintenance cost to the total investment in plant and equipment. The approximate average figures for I_3 in the steel and chemical industries are 8.6 and 3.8%, respectively.

Specific Indicators

This section presents twelve such indicators.

Index IV

This is a useful index to control preventive maintenance activity within a maintenance organization and is defined by

$$I_4 = \frac{\text{TTPM}}{\text{TTEM}} \tag{3.11}$$

where
I_4 = index parameter,
TTPM = total time spent in performing preventive maintenance,
TTEP = total time spent for the entire maintenance function.

As per the past experience, the value of I_4 should be kept within 20 and 40% limits.

Index V

This index can be used to measure the accuracy of the maintenance budget plan and is expressed by

$$I_5 = \frac{\text{TAMC}}{\text{TBMC}} \tag{3.12}$$

where
I_5 = index parameter,
TAMC = total actual maintenance cost,
TBMC = total budgeted maintenance cost.

In this case, large variances indicate the need for immediate attention.

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Index VI

This is a useful index for maintenance overhead control and is expressed by

$$I_6 = \frac{\text{TMAC}}{\text{TMC}} \tag{3.13}$$

where
I_6 = index parameter,
TMAC = total maintenance administration cost.

Index VII

This index is useful in scheduling work and is expressed as follows:

$$I_7 = \frac{\text{PJCED}}{\text{TPJ}} \tag{3.14}$$

where
I_7 = index parameter,
PJCED = total number of planned jobs completed by established due dates,
TPJ = total number of planned jobs.

The value of I_7 should be high to keep backlogs down.

Index VIII

This index is useful in material control area and is defined by

$$I_8 = \frac{\text{TPJAM}}{\text{TPJ}} \tag{3.15}$$

where
I_8 = index parameter,
TPJAM = total number of planned jobs awaiting material.

Index IX

This index can be used to measure maintenance effectiveness and is defined by

$$I_9 = \frac{\text{MHEUJ}}{\text{TMMH}} \tag{3.16}$$

where
I_9 = index parameter,
MHEUJ = man-hours of emergency and unscheduled jobs,
TMMH = total maintenance man-hours worked.

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Index X

This index can also be used to measure maintenance effectiveness and is expressed by

$$I_{10} = \frac{\text{DTCB}}{\text{TDT}} \tag{3.17}$$

where
I_{10} = index parameter,
DTCB = downtime caused by breakdowns,
TDT = total downtime.

Index XI

This is an important index used to measure inspection effectiveness and is defined by

$$I_{11} = \frac{\text{NJI}}{\text{TIC}} \tag{3.18}$$

where
I_{11} = index parameter,
NJI = number of jobs resulting from inspections,
TIC = total number of inspections completed.

Index XII

This index relates material and labor costs and is expressed by

$$I_{12} = \frac{\text{TMLC}}{\text{TMMC}} \tag{3.19}$$

where
I_{12} = index parameter,
TMLC = total maintenance labor cost,
TMMC = total maintenance materials cost.

Index XIII

This index relates maintenance cost to manufacturing cost and is defined by

$$I_{13} = \frac{\text{TMC}}{\text{TMFC}} \tag{3.20}$$

where
I_{13} = index parameter,
TMFC = total manufacturing cost.

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Index XIV

This index relates maintenance cost to man-hours worked and is expressed by

$$I_{14} = \frac{\text{TMC}}{\text{TNMW}} \tag{3.21}$$

where

I_{14} = index parameter,
TNMW = total number of man-hours worked.

Index XV

This is a useful index to monitor progress in cost reduction efforts and is defined by

$$I_{15} = \frac{\text{PMMSJ}}{\text{MCPP}} \tag{3.22}$$

where

I_{15} = index parameter,
PMMSJ = percentage of maintenance man-hours spent on scheduled jobs,
MCPP = maintenance cost per unit of production.

PROBLEMS

1. List at least ten important functions of a maintenance department.
2. What are the advantages and disadvantages of centralized maintenance?
3. Describe a nine-step approach that can be used to manage a maintenance program.
4. Discuss six important maintenance management principles.
5. List ten questions the maintenance managers can use to self-evaluate effectiveness of their overall maintenance management.
6. Discuss the following three elements of effective maintenance management:
   - Maintenance policy
   - Work order system
   - Job planning
7. Describe the following three terms associated with CPM:
   - Dummy activity
   - Critical path
   - Total float
8. Determine the critical path of network shown in Fig. 3.5 by calculating total float for each activity.
9. What are the benefits and drawbacks of CPM?
10. Define two indices that can be used to evaluate overall performance of a maintenance organization.

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